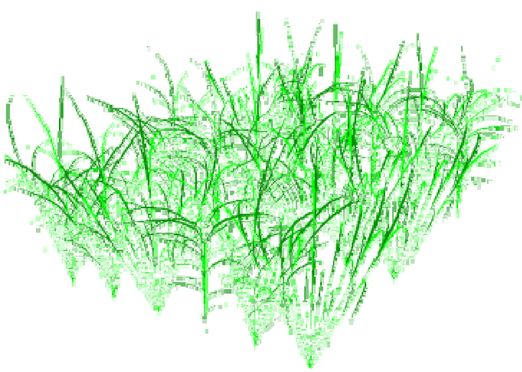
International Conference on Crop Improvement, Ideotyping and Modeling for African Cropping Systems under Climate Change (CIMAC), 2011/02/07-09, Stuttgart-Hohenheim, Germany

Phenotyping vs. ideotyping: Opportunities and Limitations of model-assisted crop design drawing from genetic diversity



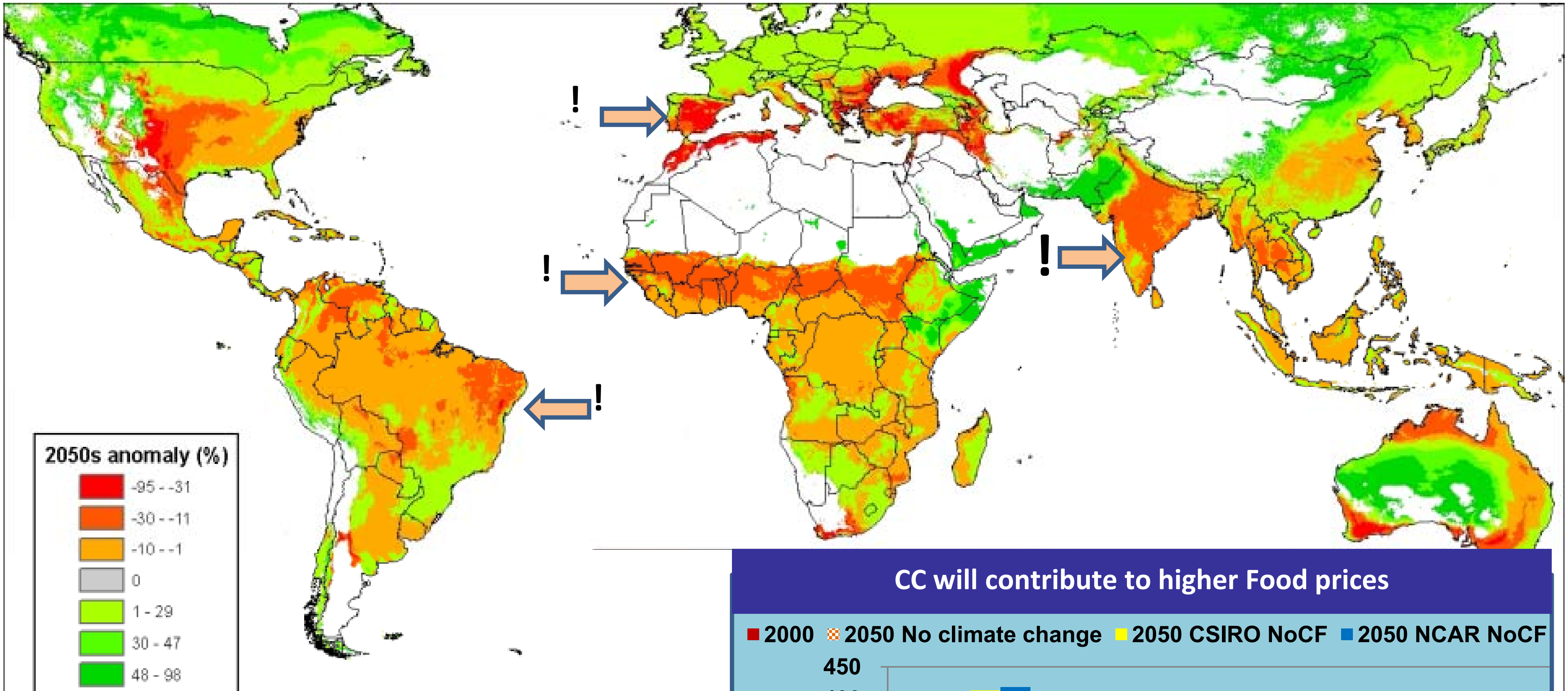
Delphine Luquet, Michael Dingkuhn

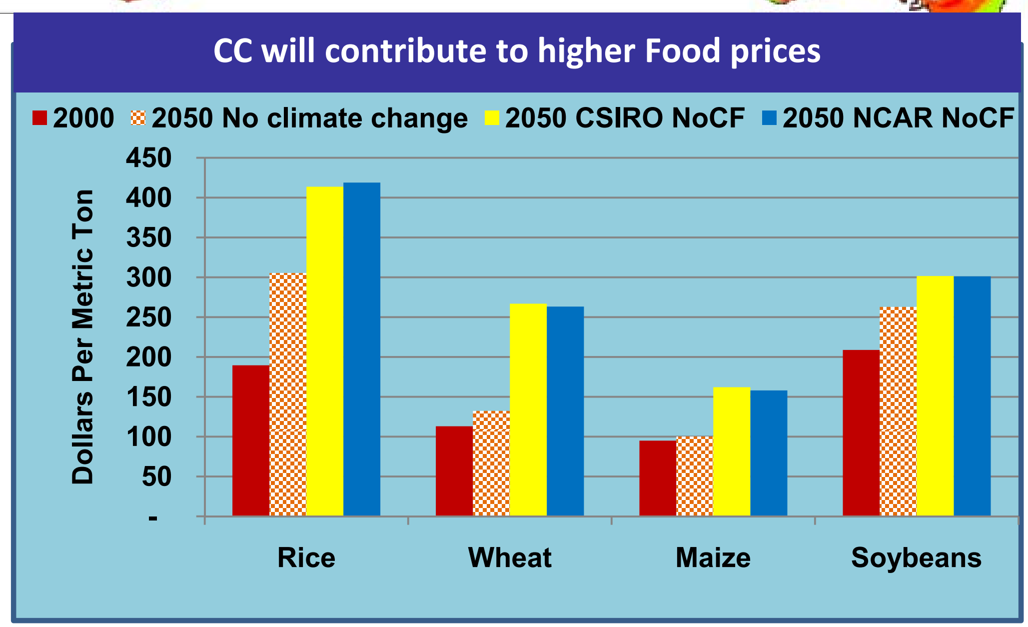
CIRAD, AGAP research unit

Montpellier, France

9th of February 2011

CC translates into increasing staple food commodity prices

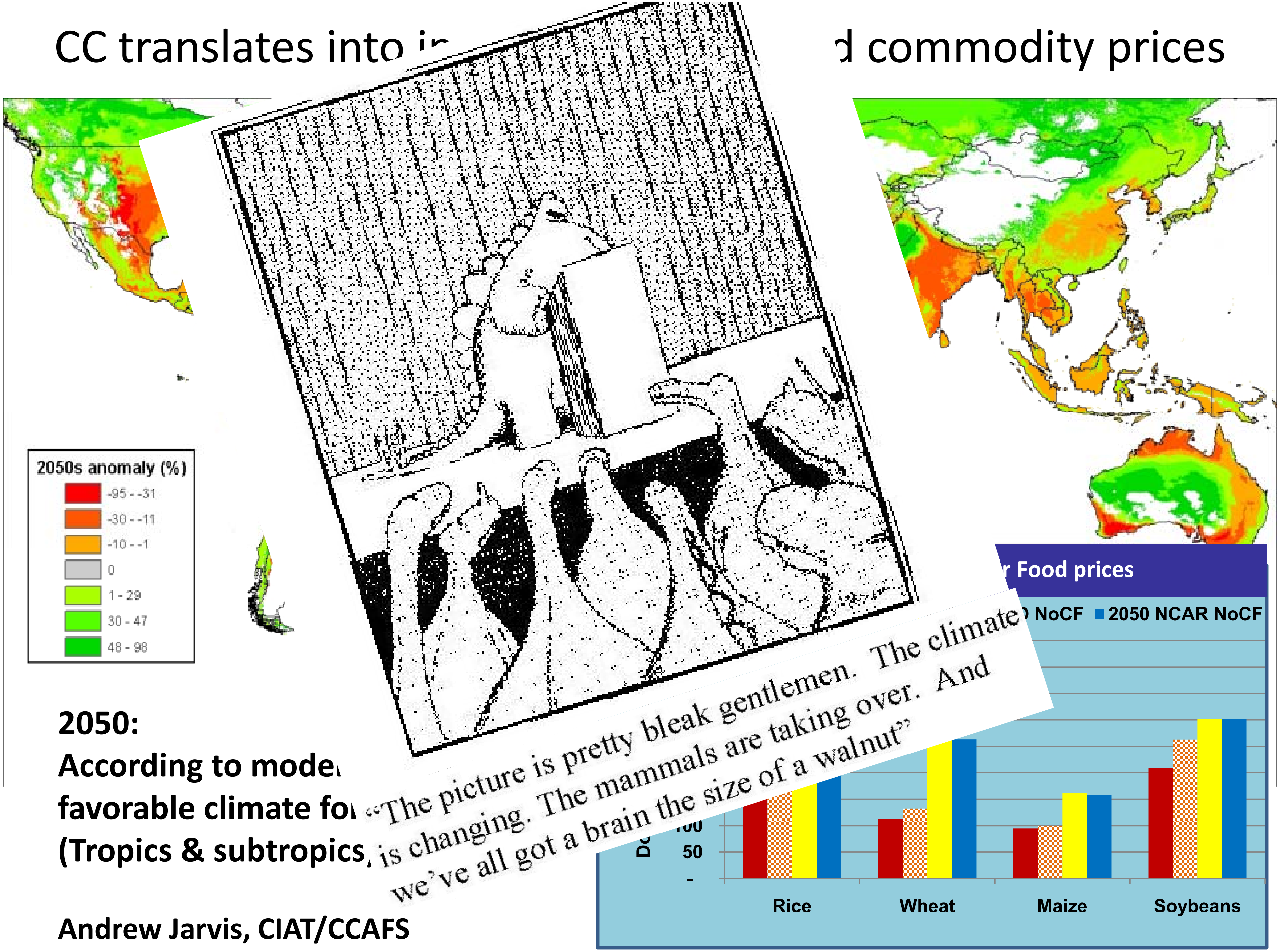




2050:
According to models, a less favorable climate for agriculture (Tropics & subtropics)

Andrew Jarvis, CIAT/CCAFS

CC translates into i... d commodity prices



2050:
According to mode
favorable climate fo
(Tropics & subtropics,

Andrew Jarvis, CIAT/CCAFS

Talk Structure

Crop improvement & CCV

Place of phenotypic plasticity

Plant modeling to support phenotyping and ideotyping

Plant modeling vs. molecular breeding:

Ongoing research

Understanding genetic & physiological architecture of complex traits

Outlook

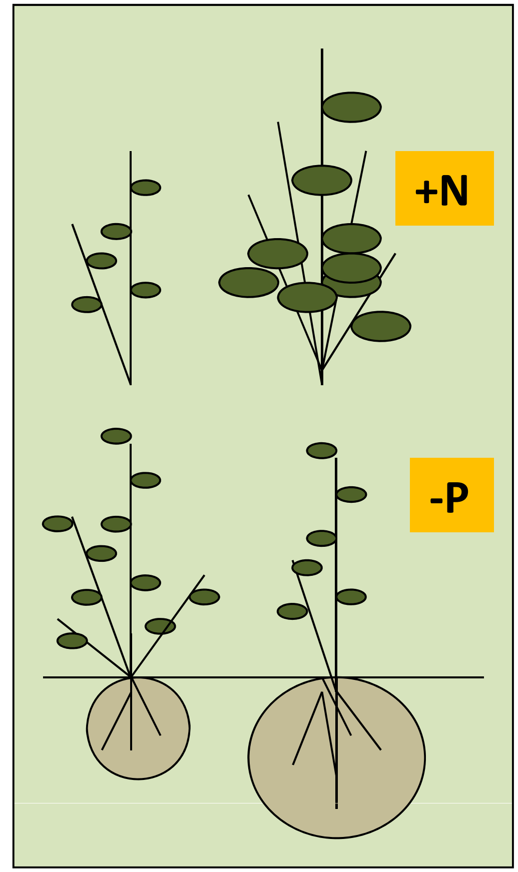
Crop improvement vs. CCV: Place for phenotypic plasticity

- What is PP?
  - Adaptive changes in plant organization during ontogenesis
  - Broad adaptation through adjustment to variable conditions
- Why needed under CC?
  - CC will increase variability
  - Water will be scarcer (water is a great stabilizator!)
    - Heat, cold, drought, salinity, soil fertility, weed competition
- Problem of trade-offs with yield pot.
  - Plastic plants = variable plant types; at what cost?
- Problem of trait complexity
  - How to measure?
  - Complex genetics?

Phenotypic plasticity

Inherent capacity to dynamically regulate morphogenesis (Nicotra *et al.* 2010)

- Based on compensatory source-sink processes
- Maintains functioning, reproduction & production when conditions fluctuate
- Includes more than morphology: Phenology, physiological defenses…



Examples of traits needed under greater climatic variability

Phenology

- Adaptive phase duration (temporal compensation and stress escape)
- Rapid development for vigour and high yield potential under short duration

Morphology

- Architecture limiting stress exposure and maximizing resource effiency
- Environment responsive morphogenesis

Physiology

- Effective and rapidly inducible tolerance; Hardening?
- Protection of reproductive processes (e.g., cooling of spikelets)

Implications of phenotypic plasticity

- Increase of G x E
- Intelligent use of G x E through management & forecasts
- Avoid or overcome counter-productive plasticity
  - trade-off on yield (Nicotra *et al.* 2010)
- Trade-offs among multiple yield objectives
  - e.g. sweet sorghum for ‘FFF’ (Gutjahr *et al.* 2010)

Challenge:

Conceive plants having 'productive' plasticity

Lesson from the past: start from available genetic diversity, not wishful physiological thinking

Understand physiological and genetic architecture of complex traits

Reduce complex traits to component traits, recombine intelligently

Give room to discovery, and build it in

Plant modeling to support phenotyping & ideotyping

Adapting the Ideotype concept

Morphology & Phenology

- Green revolution for favorable conditions
  - Dwarfing => High tillering & HI, less lodging => N responsive
- Make traditional systems more productive
  - Combine PP-sensitivity with green revolution traits (African sorghums)

Morphology, phenology and biochemistry

- Multi-purpose, new purposes
  - Grain/forage cowpea, peanut… (FF)
  - Sweet grain/bioEtOH/forage sorghum (FFF)
  - Biomass 2nd generation energy Annuals/Trees
  - C-sequestering food/forage crops

Most difficult: Change ecophysiological adaptation (T, drought, CO_2)

- Combine multiple adaptations with desired plant type
- Transform metabolic type (C4 rice)
- Transform harvestable product (‘rice ’-sorghum?)

3 steps in Ideotype development where crop models can help

- Characterization of Target Populations of Environments (TPE), incl. CC scenarios

  => Use simple agronomic crop model as "lens"

- Identification of target trait combinations & plant types for TPE

  => Use crop model with GxExM skills to simulate trait expression & adaptive value

- Phenotyping process => Association studies => Markers

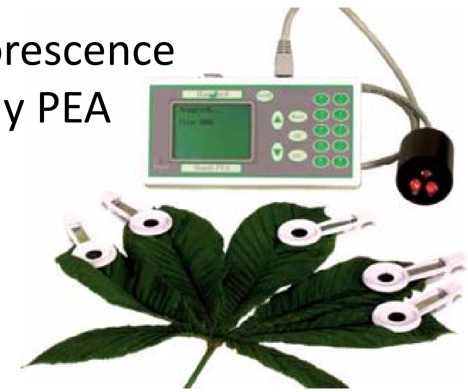
  Heuristics: Extraction of trait parameters from observed variables

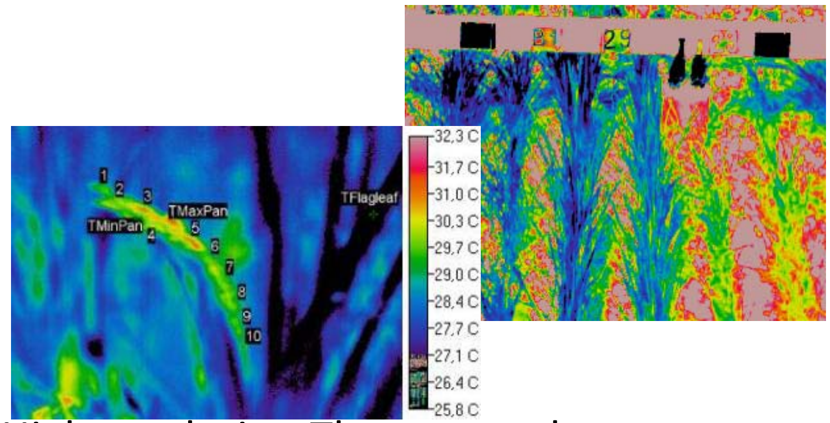
  => Specialized process models with small parameter nb.

Role of plant physiology and modelling in plant breeding: phenotyping

- Novel tools (imagery, remote sensing): maximize data acquisition on large number of plants

Rapid fluorescence
OJIP Handy PEA

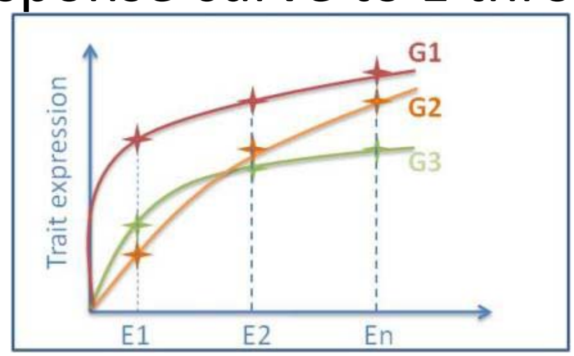




High resolution Thermography

⇨ Still need to decorrelate G and E effects (modelling)

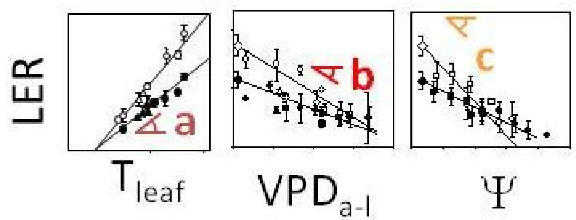
- Models needed that analyze & predict G response curve to E through genotypic parameters



Example of role of modelling in phenotyping

Leaf expansion rate response to drought variables (maize)

Raymond et al. (2003, 2004)

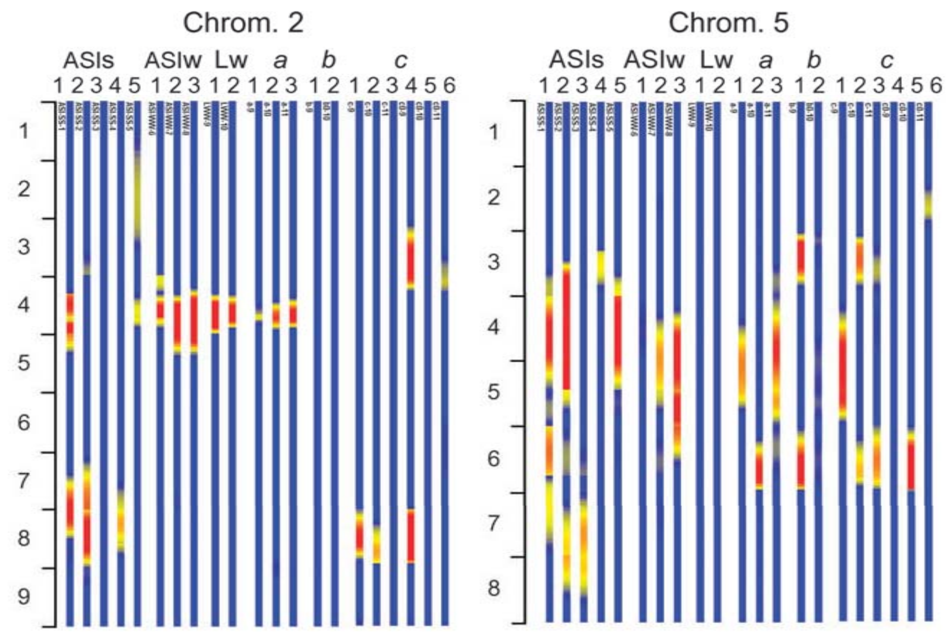


$$LER = dl/dt = (T - T_0)(a + b\ VPD_{air\text{-}leaf} + c\ \Psi)$$

$$a = \bar{a} + \sum \alpha\ QTL$$

$$b = \bar{b} + \sum \beta\ QTL$$

$$c = \bar{c} + \sum \gamma\ QTL$$



Welcker et al. 2007

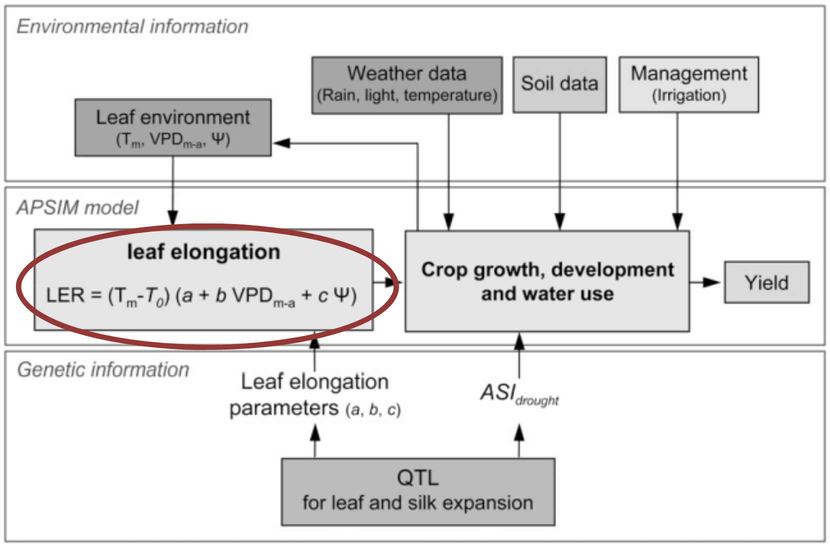
- **LER model QTLs colocate** with that of **direct measurements** (leaf width)
- **More stable** across E : **QTLxE overcome** (modeling the cause of QTL instability)
- **Validated in contrasting genetic background** (temperate to tropical)
- LER model QTLs **colocate with silk expansion QTLs (ASI): 2 crucial traits in 1!**

From relevant QTLs to ideotype: integrative process

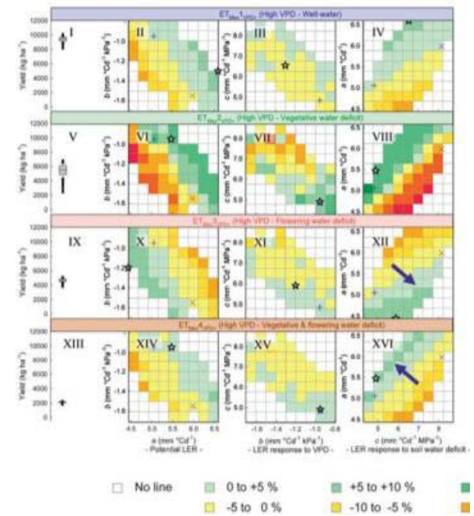
- QTL validation = evaluation at plant/pop. scale (crop performance): **When expressed? When relevant?**
- Modelling must predict accurate G x E x M interactions and trade-offs (Hammer *et al.* 2010)
- Even more challenging when addressing CCV (extrapolation)

Example of role of modelling in phenotyping (cont.)

Incorporation of LER model in APSIM (maize)



Simulated effect of LER-QTLs on yield

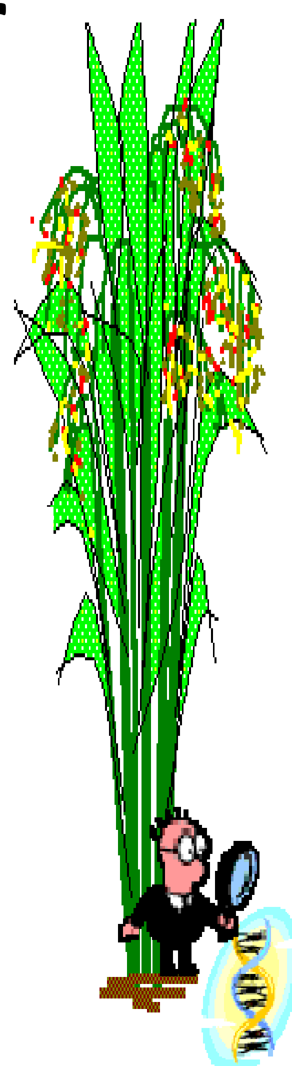


From Chenu et al. 2009 ; Genetics

⇨ First real **proof of concept for ideotype simulation** using crop models driven by genetic parameters

⇨ Doing this for traits for **phenotypic plasticity** requires models with greater detail of trait interactions (morpho/pheno/physio)

Can plant modeling assist molecular breeding by analyzing genetic & physiological architecture of complex traits?



Ongoing work

Vision: Massive use of molecular markers for agronomic traits and agroecological adaptation

Rice & sorghum are sequenced

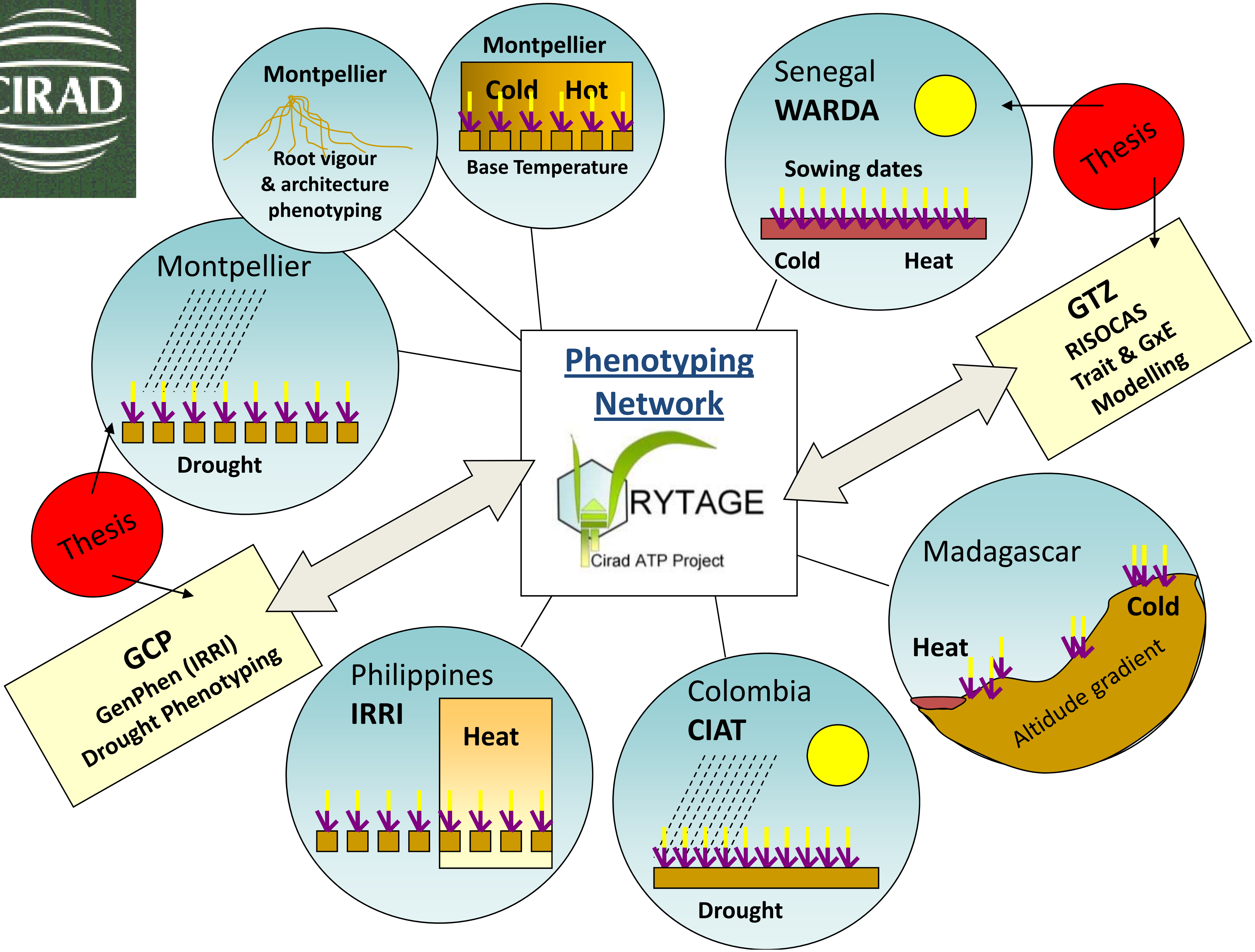
Mass sequencing of rice genomes planned

Sorghum is a major source of genes in C4 rice project

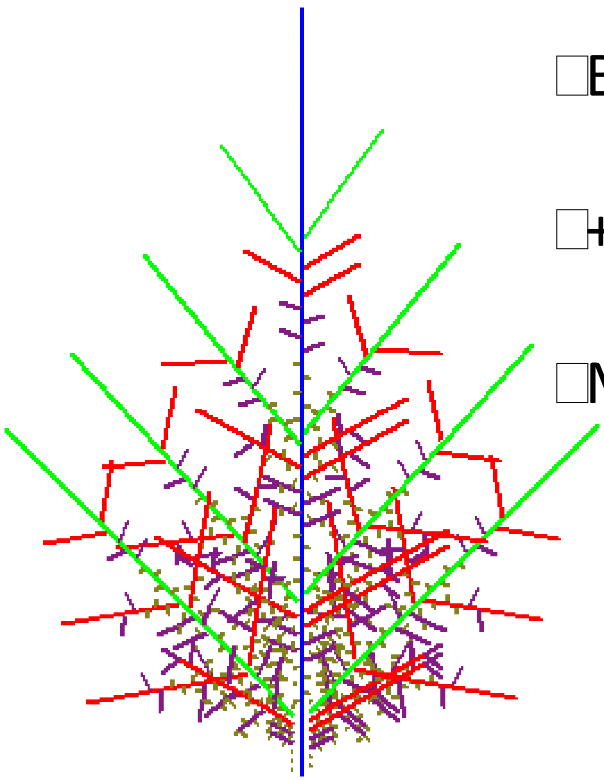
Mass application of MAS in private seed sector

GRiSP plan for global phenotyping & gene discovery & molecular breeding networks

CC&FS plan for ideotype strategies for 2030 CC horizon


Phenotyping Network
RYTAGE
Cirad ATP Project
Montpellier
Root vigour
& architecture
phenotyping
Montpellier
Cold Hot
Base Temperature
Senegal
WARDA
Sowing dates
Cold
Heat
Thesis
GTZ
RISOCAS
Trait & GxE
Modelling
Montpellier
Drought
Thesis
GCP
GenPhen (IRRI)
Drought Phenotyping
Madagascar
Cold
Heat
Altidude gradient
Philippines
IRRI
Heat
Colombia
CIAT
Drought

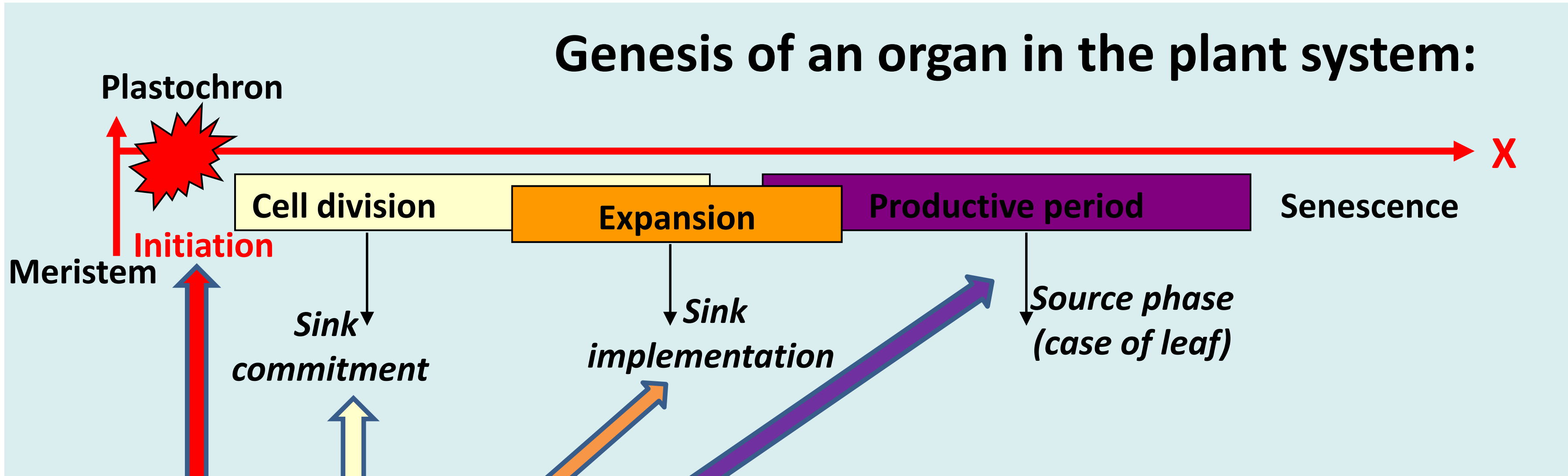
Dealing with traits regulating whole plant morphogenesis

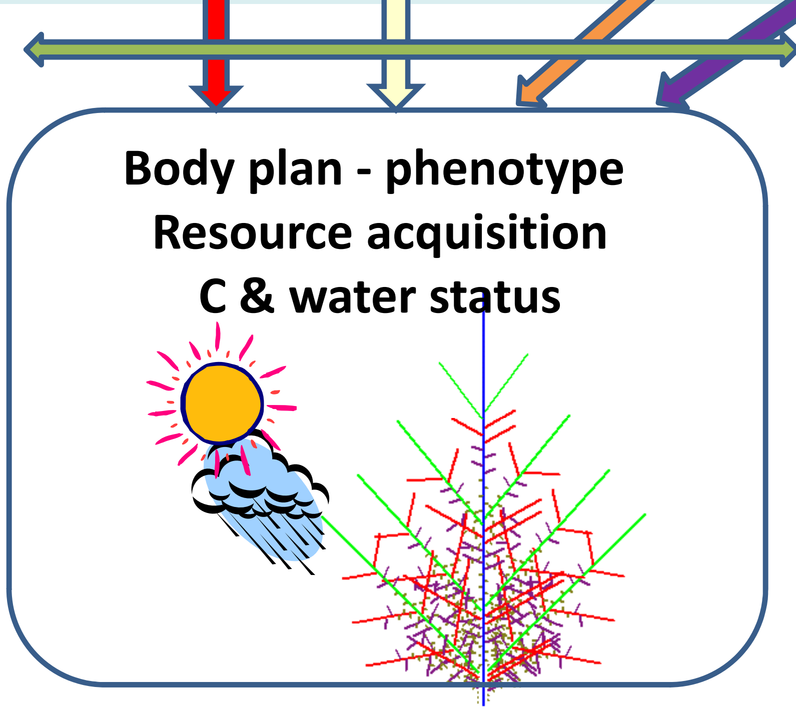


- Body plan construction
- +/- plastic in response to E depending on G
- Many processes related to **meristem activity**
  - tillering, leaf initiation, size, expansion…

Important: Simulation of Outcomes vs. Forcing!

Example: Partitioning handled differently ifor agronomic or genetic objectives





Consequences:

- Demand determined ***before*** growth
- Demand regulated to match supply
- Supply feedbacks on meristem behaviour

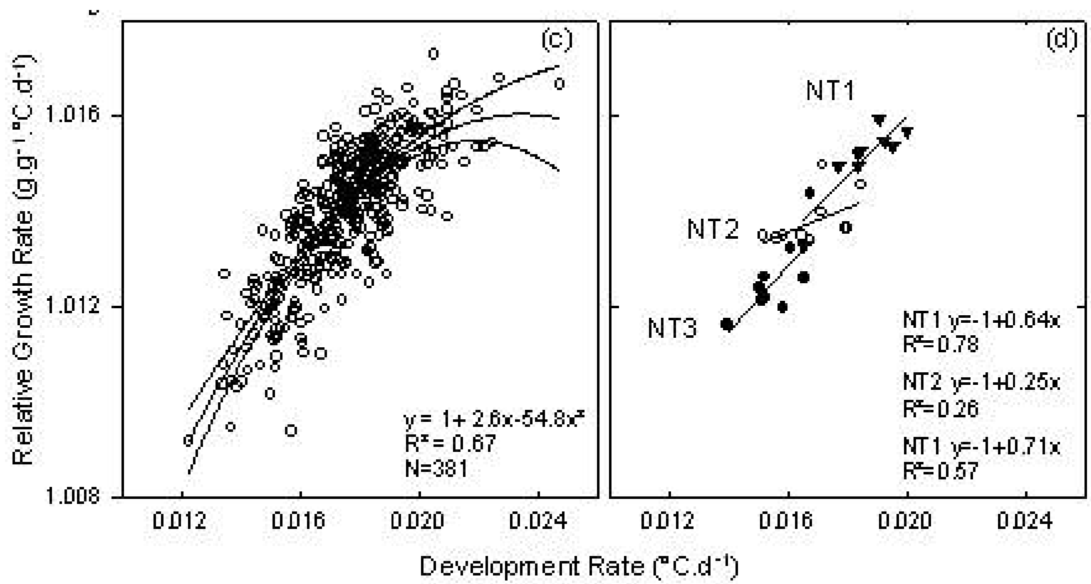
⇨ **Physiological linkage (trade-off) among traits** (Rebolledo et al 2010; Granier & Tardieu 2009)

⇨ **Also genetic linkage** (organ cell vs. organ n°) (W ter Steege et al. 2005; Tisné et al. 2008)

⇨ Rebolledo :
phenotyping for **absence of linkage**?

Development rate DR (1/phyllochron) impact on rice early vigour

CIRAD, greenhouse (2009), 203 japonica cvs.; pot, well watered and stressed



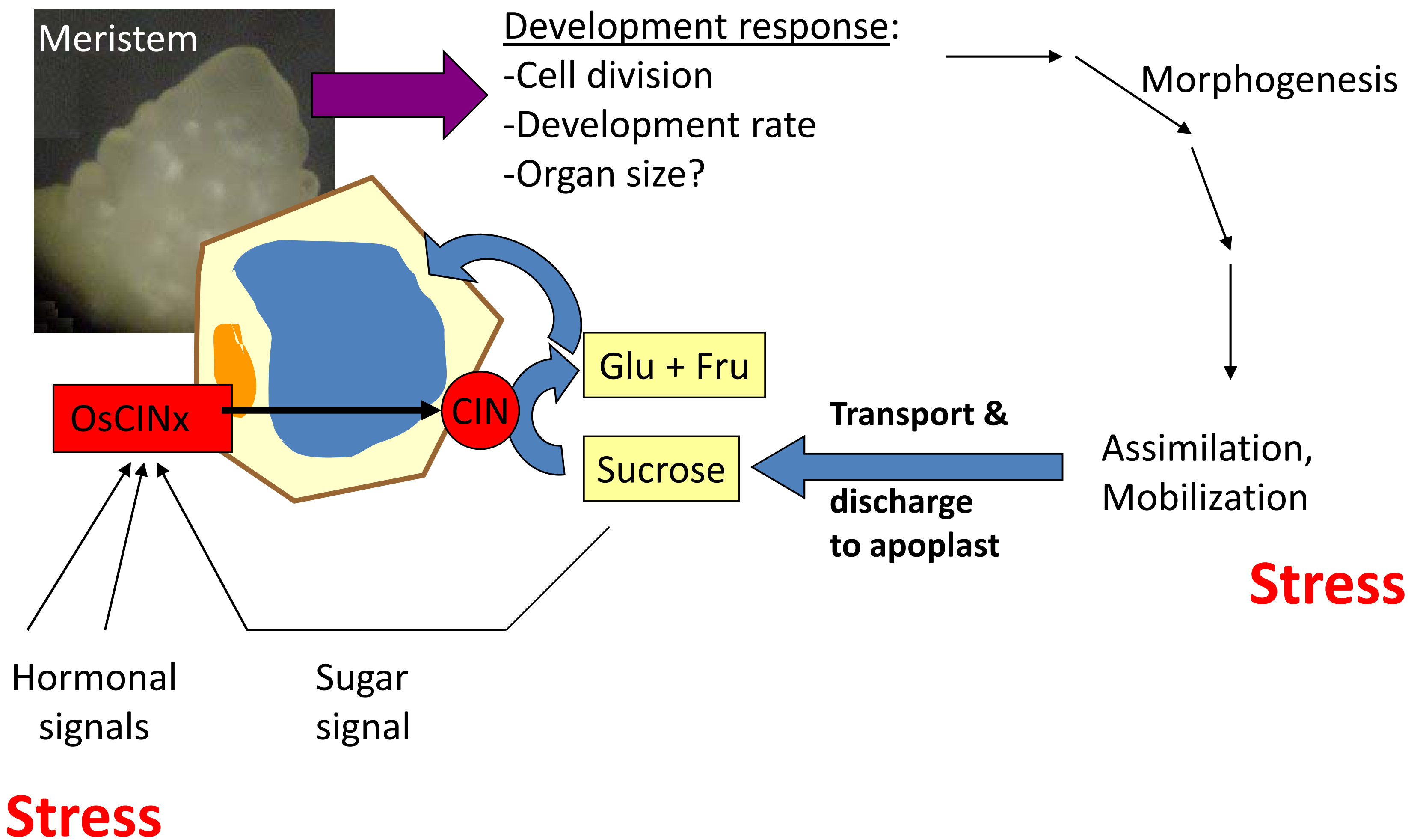
⇒ **DR main trait explaining vigor** (RGR) under well watered and drought conditions

⇒ **Holds up at constant tillering & leaf size**

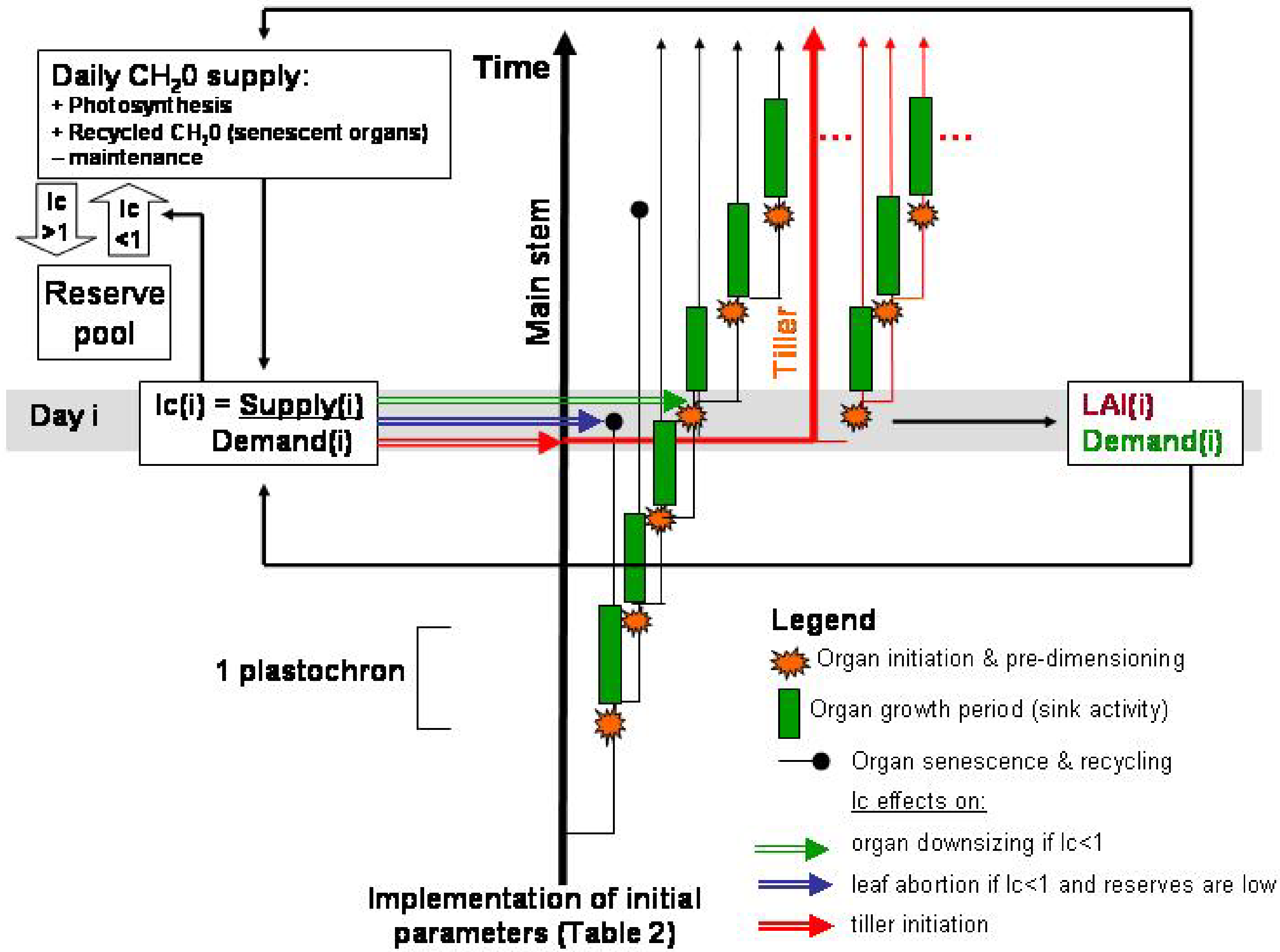
⇔ **Direct effect of DR**

⇔ **<u>trait genetic independence?</u>**

Issue of signaling
Sink adjustment by growth/development process feedbacks

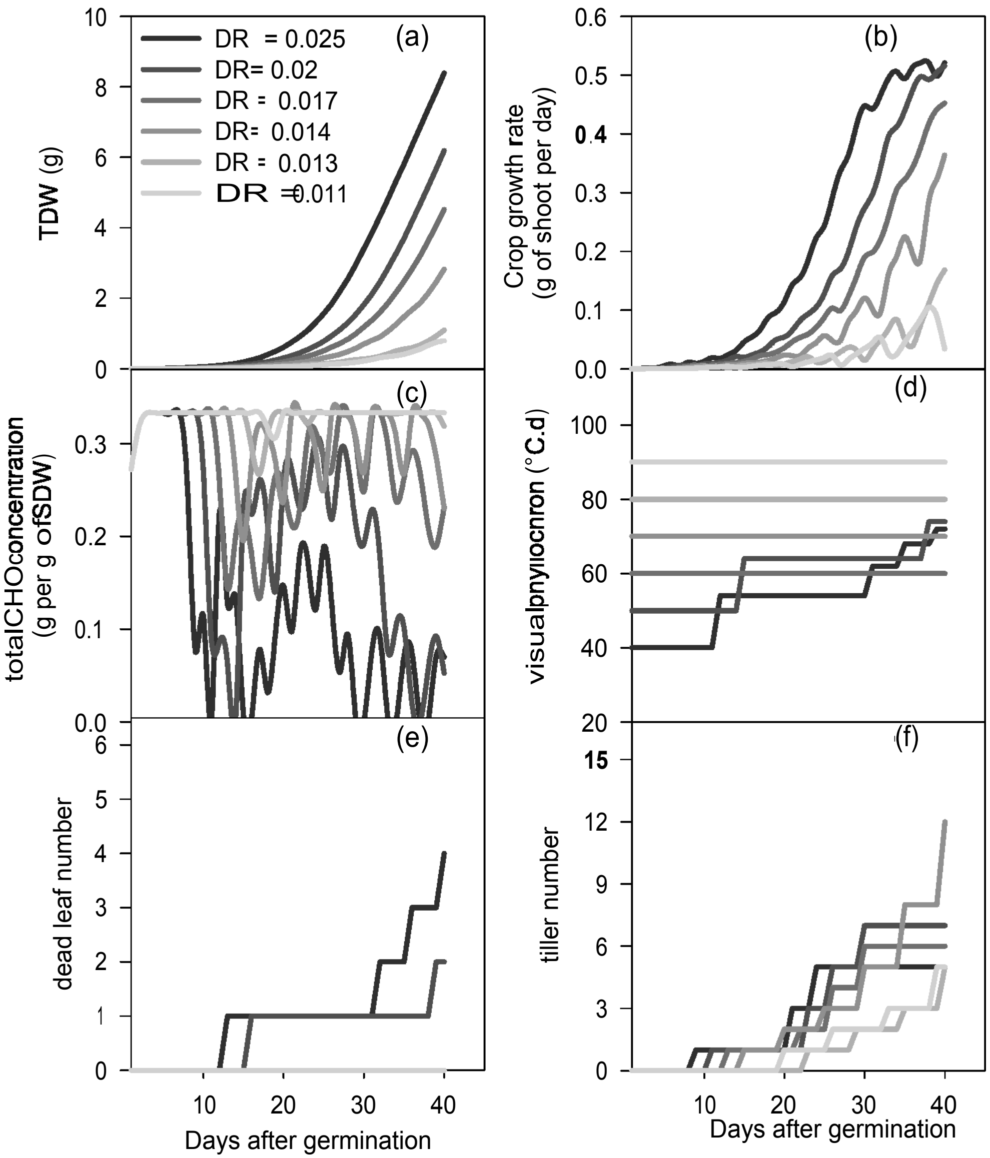


EcoMeristem, model of phenotypic plasticity



Ic = index of internal competition = proxy for sugar availability = internal signal

Simulation experiment with Ecomeristem Source-sink processes vs. DR



6 DR values, else parameters constant

40 day simulations

Rapid DR increases...

- growth rate
- **transitory reserve depletion**
- tillering

But can also cause « trophic crisis »

- **delayed leaf appearance**
- smaller leaves
- accelerated leaf senescence

During drought:

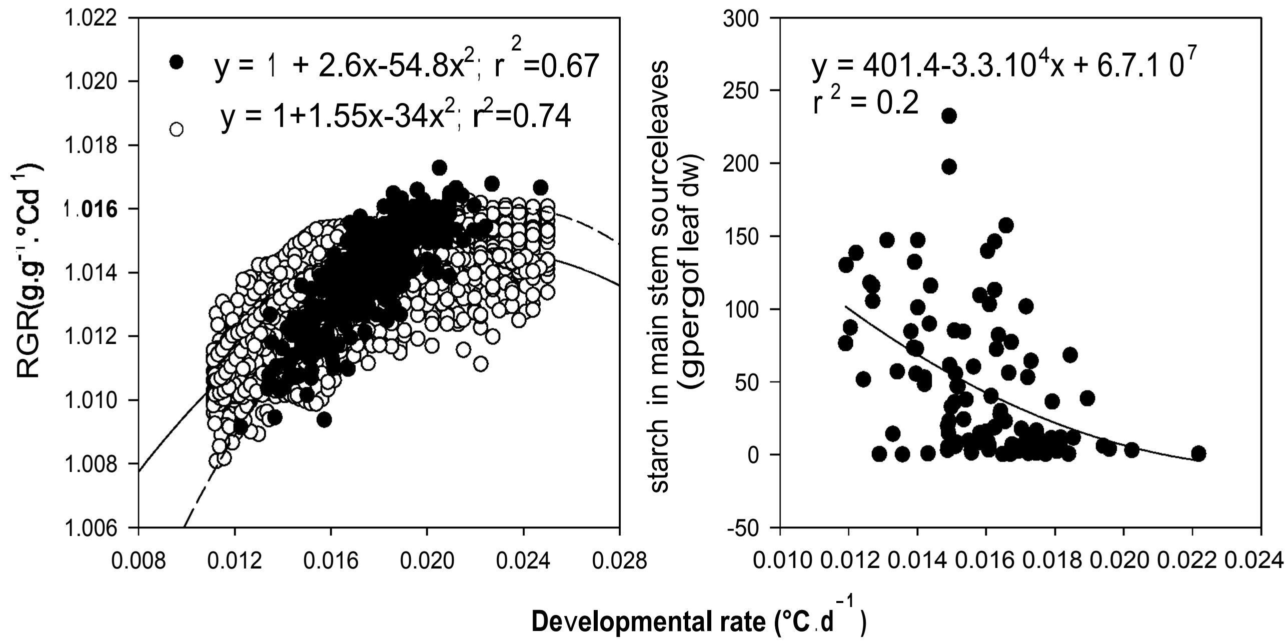
- Stress more severe (because of greater water use)

... Followed by faster recovery

Natural genetic diversity cs. potential (in-silico) diversity

Natural vs. in-silico population (performance of model parameter combinations)

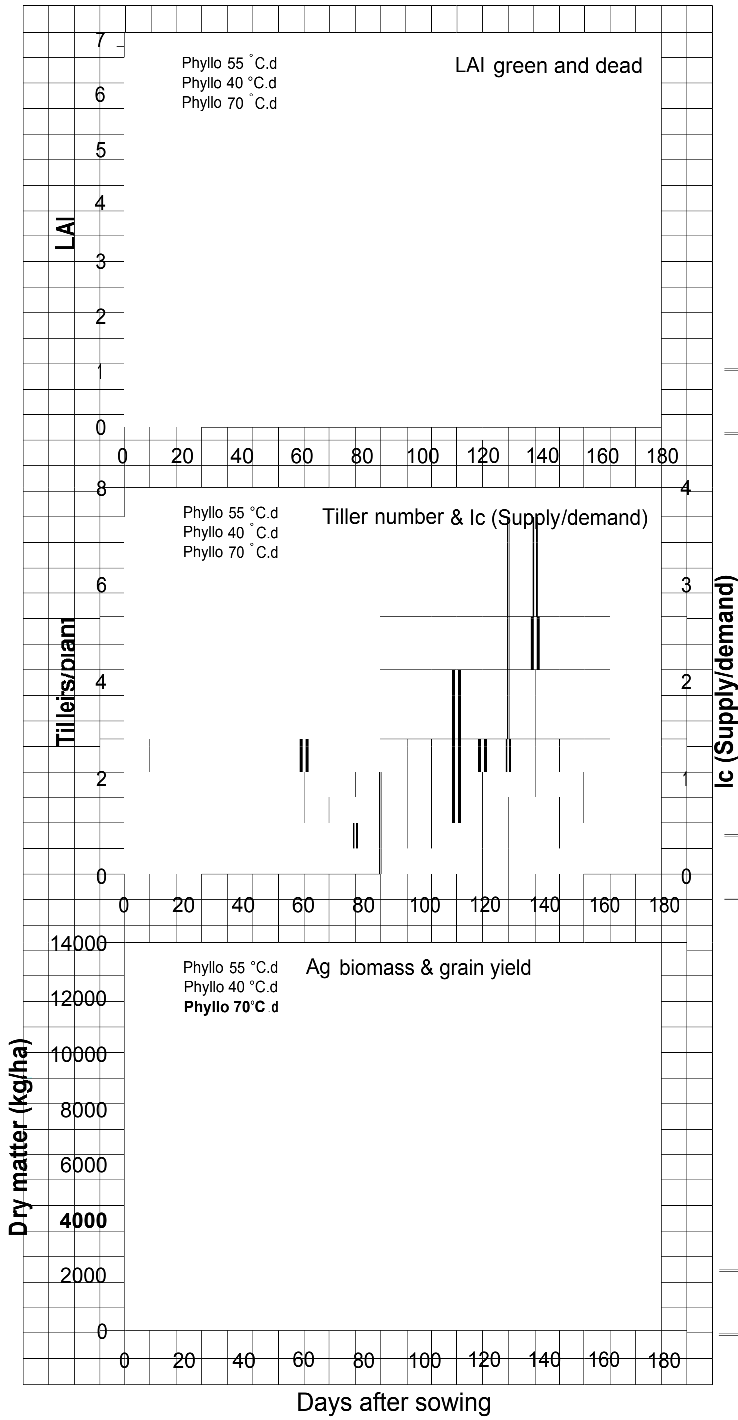
Natural relationship of Reserves vs. DR



Contribution of parameters to DR in natural **p**o**p**ulation

	MGR	Ict	Epsib	*plasto*	Adjusted R^2
1 variable				X	0,17
2variables			**X**	**X**	**0,28**
3 variables		X	X	X	0,52
4 variables	X	X	X	X	0,55

SAMARA (Risocas product): Predicting GxExM of process traits in an agronomic context



Fast development increases LAI
But leads to early leaf senescence

Fast development provides for earlier tillering
But causes tiller abortion due to competition

Fast development affects biomass yield little
But reduces grain yield (small panicles, poor sink)

Outlook

Analytical modeling:

Reductionist vs integrative (complex) process models

Reduce error and calibration effort for complex models

Phenotyping:

Methodologies to capture regulation of key processes

Phenotype specifically, think systemically

Eagerly awaiting the moment of truth:

Phenotyping done (w/ & w/o models): internatl. Network

Genotyping awaits 600-K SNPs chip

Major loci/alleles? Co-location for different stresses/traits?

Physiologists, be ready for unexpected eye openers!

Merci